546

VOLUME 80 SEPARATE No. 546

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

NOVEMBER, 1954

INTERRELATION OF STREAM REGULATION AND STREAM POLLUTION

by Charles M. Davidson and
Milo A. Churchill, A.M. ASCE

SANITARY ENGINEERING DIVISION

{Discussion open until March 1, 1955}

Copyright 1954 by the AMERICAN SOCIETY OF CIVIL ENGINEERS
Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings — Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

Reprints from this publication may be made on condition that the full title of paper, name of author, page reference (or paper number), and date of publication by the Society are given.

The Society is not responsible for any statement made or opinion expressed in its publications.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

INTERRELATION OF STREAM REGULATION AND STREAM POLLUTION

Charles M. Davidson[1] and Milo A. Churchill[2] Assoc. M. ASCE

INTRODUCTION

At the present time there are 30 major dams and a number of minor ones which make up the integrated water control system in the Tennessee Valley. The dams were built primarily for flood control, navigation, and power generation. It is apparent that such an extensive and coordinated system of reservoirs and stream-flow regulating structures will have a significant effect on the pattern of flows in the major streams of the Valley. The principal effect has been to reduce flood flows and increase the general level of low flows. On the principal tributary streams, however, where the major storage reservoirs are located, although the general level of low flows has been raised, it is common practice to shut off the flow at the dam completely on weekends and during other periods of off-peak power loads.

In addition to the quantitative changes in flow, the system of impoundments produces significant changes in the physical, chemical, and biological characteristics of the impounded waters. These changes exert both beneficial and detrimental effects on downstream quality and uses. Some downstream uses have been enhanced to a remarkable degree, others measurably benefited, and at a few locations some detrimental effects have been noted, particularly where inflowing impounded waters are seriously polluted with industrial or domestic wastes.

This paper discusses some of the inter-relations between stream regulation and stream pollution. A number of fundamental principles have been established that will be found generally applicable in similar circumstances. Many questions are involved and answers to some of these have been found but others have not been solved. Although primary consideration is given statutory purposes in reservoir operation, work is continuing in the Tennessee Valley toward the ultimate goal of finding the method of operating multi-purpose reservoirs that will maximize the beneficial effects and minimize the detrimental ones.

Characteristics of Flow Through a Large Headwater Storage Reservoir

An understanding of the hydraulics of flow through a large reservoir is fundamental to the understanding of physical, chemical, and biological differences observed in the inflowing and outflowing waters.

In the Tennessee Valley the storage reservoirs are operated on an annual cycle. They are drawn down in the late summer and fall to reach a predetermined minimum flood-control level by January 1. As the probability of heavy

1. Chief, Environmental Hygiene Branch, Division of Health and Safety, Tennessee Valley Authority, Chattanooga, Tennessee.
2. Chief, Stream Pollution Control Section, Division of Health and Safety, Tennessee Valley Authority, Chattanooga, Tennessee.

flood-producing rains decreases with advancing spring, the pools are gradually filled. They reach and maintain their highest levels during the early summer months.

During the colder winter months of the year the inflowing water has essentially the same temperature and density as the pooled water. The inflowing water, therefore, occupies the entire cross section of the reservoir as it advances slowly toward the dam under the influence of draft at the dam. As it moves downstream, it circulates from water surface to reservoir bottom due to wind action and fluctuating air temperatures.

As spring advances the temperature of the inflowing water rises. The incoming water is then lighter than the impounded waters and consequently, it flows over the top of the pooled water which does not respond to seasonal changes so rapidly. Thermal stratification becomes established early in the spring and continues throughout the summer. Water entering the pool during this entire period flows into the epilimnion above the thermocline where it circulates between the water surface and the upper levels of the thermocline. The thermocline effectively seals off the water below it from contact with water in the epilimnion and from the water surface.

Water is discharged at the dams through low-level outlets. As summer advances, the horizontal thermocline is gradually lowered as the cold winter water of the hypolimnion below the thermocline is steadily removed by draft through the turbines. In the large reservoirs the volume of cold water below the thermocline is generally sufficient to supply primary purpose requirements during the summer months. Usually by fall the horizontal thermocline is nearing the bottom of the pool and the discharged water is drawn from the lower levels of the thermocline. Then the hypolimnion is non-existent and the thickened epilimnion occupies practically the entire pool.

In the fall of the year, the inflowing waters respond to seasonal cooling more rapidly than does the great mass of pooled water. As a result, the incoming water soon becomes colder, and consequently, more dense than any water in the pool. It flows through the pool, therefore, as a density current along the bottom. The velocity of this underflow is usually a few tenths of a foot per second. At this velocity the water short circuits all the stored water and is discharged at the dam within two or three weeks of the time it enters the pool.

As winter approaches, the temperature of the pooled water is gradually decreased. The shallow upper end of the pool responds more rapidly than the main body of the pool and about the middle of December, vertical circulation throughout the length and depth of the pool has been established. Winter stagnation does not occur at the latitudes of the Tennessee Valley, so vertical circulation continues all winter.

Effects of Storage on Water Quality

Stream flow regulation supplies many benefits over and above those resulting from flood control, navigation, and generation of power. It cannot be expected, however, to cure all the evils of stream pollution and should in no sense be used to absolve the polluter from making suitable corrections in waste disposal.

Obviously, the first consideration of storage effects centers on the bacterial quality of the raw water. Some 400,000 residents of municipalities and towns in the Tennessee Valley depend upon TVA reservoirs, or the controlled streams below the reservoirs, for water supply. The coliform content of the water is of basic importance. As early as 1913 the benefit to be derivedfrom

prolonged storage of water in lakes had been clearly established. A survey by the International Joint Commission showed that while the Detroit River entered Lake Erie with several hundred E. Coli per milliliter, these organisms did not exist in 100-milliliter samples from the center of the lake.[3]

Cherokee Reservoir, one of the largest TVA storage reservoirs, impounds the Holston River above Knoxville. At maximum elevation it is 59 miles long and provides 1,565,400 acre feet of storage. Bacteriological studies were made for the period March 1945-March 1946. Inflowing and discharged waters were sampled at about four-day intervals. The arithmetic mean coliform concentration of the inflowing water was 3390 per 100 milliliters, and that of the discharged water was 103 per 100 milliliters. Coliform concentrations in the discharged water were appreciably higher during the winter months than during the summer. Summer concentrations were in the range of 10 to 20 per 100 milliliters.

Of equal interest is a bacteriological study made in the Tennessee River below Knoxville.[4] In 1936, at a point 22 miles below Knoxville and prior to impoundment of this stretch of the main river by Fort Loudoun Dam, coliform organisms averaged 14,000 per 100 milliliters. At this location in 1944 after impoundment but with the same stream flow, the average was about 1000 per 100 milliliters.

Percentagewise, even more reduction occurred at the Chattanooga raw water intake. During the year 1936, the bacterial plate count averaged 12,000 per milliliter. Following impoundage of upstream reservoirs, the bacterial plate count averaged 300 per milliliter in 1948. This is a 97.5 percent reduction.

These notable differences in coliform concentration are not limited in value to the use for drinking water alone. The recreational benefits, particularly as regards swimming, are great and often not fully realized. For example, the quality of water in the lower end of Chickamauga reservoir above Chattanooga approaches that of the early Drinking Water Standards. Broad expanses of shoreline lands along the major main river reservoirs have been transferred to states and municipalities for parks and playgrounds. Private and commercial developments have taken and continue to take advantage of the vast recreation potential.

Sediment in the run-off waters is readily diminished on entering the quiet waters in the upper end of the reservoirs and turbidities have been radically reduced. Average annual turbidity has decreased 78 percent at Chattanooga and 61 percent at Knoxville. One may wonder how long it may require this continual siltation effect to become a problem. Improved land management practices adopted early and fairly widespread throughout the watershed, serve to retard soil removal. TVA studies prior to and following impoundage show that from one thousand to four thousand years will be required to fill any major TVA reservoir with silt.

Most streams in the Tennessee River system are free of noticeable color. However, those river reaches below pulp and paper mills are not free of color. While such stream sections do not comprise a major portion of the system, this form of pollution is readily detectable and resented by the public. Inasmuch as the organic material producing the color is relatively immune to

3. Stream Sanitation. Earle B. Phelps 1944 p. 201-202.
4. "Bacteriological Studies of the Fort Loudoun Reservoir" by R. N. Clark and F. W. Kittrell, Journal APHA, March 1948, p. 342-350.

biochemical action, dilution (or high turbidity) is about the only natural purification force that can bring about material improvement in any reasonable river distance. A study by one of the authors on reduction of color from paper mill wastes discharged into the Little Tennessee River system, which flows through Fontana Reservoir, showed that a major color reduction occurred in the reservoir.[5] This reservoir when full is 450 feet deep at the dam and provides 1,444,300 acre feet of storage. The minimum retention period in the reservoir is about 2-1/2 months.

One of the most striking effects on water quality below the storage dams is reduced temperature. In 1949, daily temperature readings were made at the filter plant of an industrial concern taking raw water from the Watauga River downstream from Watauga Dam. Prior to impoundage, the temperature varied from a minimum of 38° F. in January to a maximum of 79° F. in July. The average water temperature for the period June, July, and August 1949 was 71.7° F. In 1950, after impoundage, temperatures varied from 41° F. in December to 67° F. in September. For the three months of June, July, and August, the average temperature was 57.6° F. with a maximum variation of only 10°. The variation was produced by changes in the proportion of local inflow in the total flow of the river at the filter plant.

Water released from Norris Reservoir on the Clinch River above Oak Ridge has a temperature ranging from 40° F. to 50° F. most of the summer and it usually does not rise above 65° F. even in the fall when the supply of cold water is nearing exhaustion due to draft from below the thermocline.

The abundance of cold water with but slight seasonal variation cannot be too strongly emphasized. Presently, it is one of the great unused natural assets of stream regulation. Two of TVA's stream plants for the generation of electric power are so located as to take some advantage of the available cold water from Norris Reservoir for use in condensers. A few other industrial installations in the Valley are also benefitting, mostly by virtue of being located below sites where TVA reservoirs were later built. By and large, however, the almost unbelievable savings to industry in fuel consumption to be had by using cold water in steam condensers, are not being realized.

A reservoir usually has a very effective "smoothing out" effect on variation in chemical quality that may be produced by upstream pollution. Obviously, the deep storage pools are most effective in this regard. However, during the fall of the year when density underflows occur, even the storage pools fail to dampen variations in quality completely.

Along with the many beneficial effects of reservoir storage on water quality, there are a few detrimental effects that need discussion. When water is stored for long periods in a reservoir, much, if not all, of the dissolved oxygen below the thermocline is exhausted by natural organic materials present even in so-called clean, or unpolluted waters. If the stored water is polluted by organic wastes, the available dissolved oxygen is depleted much more promptly and completely.

Since the water so affected is effectively sealed off from surface reaeration, it remains low or devoid of dissolved oxygen until discharged from the dam through the power units. If a great excess of carbonaceous polluting material is present, any existing sulfates will be reduced to malodorus sulfides. These odors will be quite noticeable in the tailrace of the dam.

---

5. "Natural Reduction of Paper Mill Color in Streams" by M. A. Churchill, Sewage and Industrial Wastes, Vol. 23, No. 5, 1951.

During the summer months when water low in dissolved oxygen is discharged from the dam, the capacity of this water to assimilate any additional pollution discharged into it by downstream municipalities or industries is materially reduced below that of an equal flow under unregulated conditions.

It is apparent that in the evaluation of pollution loads discharged into a reservoir, and the effects thereof, it is necessary to incubate BOD samples for long periods of time. Five-day BOD values have but limited value in such studies.

Effects of Changes In The Flow Pattern On Down Stream Waste Disposal

Streams receiving suspended organic wastes transport them varying distances. The finely divided material remains for a long time in a suspended or collodial state while heavier waste is deposited to form sludge banks. These deposits exert what may be an important oxygen demand on the flowing water. In most unregulated streams flood flows remove these sludge beds at frequent intervals, thereby creating conditions more favorable for the assimilation of other oxygen demanding wastes. With flood flows eliminated by the construction of storage dams, sludge beds continue to enlarge and usurp disproportionate amounts of dissolved oxygen from the water flowing over the beds. This effect may not be detrimental to the stream as a whole, but in the stream section immediately below the waste discharge, a nuisance may occur.

Obviously, water in a multipurpose storage reservoir cannot accomplish even the primary objectives unless it is released accordingly. There are high-classification uses, however, such as for water supplies that may require continuous flow. Below most of the storage projects the average flow during the low-flow season is at a higher rate than prior to impoundage. During daylight hours power demands are met by more or less steady discharges through the turbines, but after the load decreases at night and on weekends, economy in the use of water for the power program requires that the discharge be reduced as low as possible or cut off.

The consequences of this intermittent flow pattern as it relates to dilution of pollution is one of the unanswered questions under study.

It is recognized that a careful evaluation must be made of the value to the region of the various, and often competing, uses of the available water.

Sampling Problems Due To Differences In Wave and Water Travel

In those situations where a significant amount of pollution is discharged to the river at locations only a few miles downstream from a storage reservoir, a number of interesting and yet exasperating problems are presented in connection with the quantitative evaluation of the pollution load and its detrimental effects.

Since the discharge of the controlled river will fluctuate between wide limits daily, the pollution at the point of discharge to the river receives great dilution during periods of high flow but much less dilution during those periods of the day when the only flow in the river is that due to local inflow below the dam. If the pollution is discharged to the river at a steady rate, the concentration in the stream after mixing with the available flow, but at locations relatively close to the point of pollution, will be found inversely proportional to the flow in the river. However, as the water moves downstream this inverse proportion is progressively altered due to the hydraulic fact that a translatory wave of high stream flow, produced by power releases at the dam,

moves downstream much faster than the water itself which composes the wave. To those unacquainted with the hydraulics of translatory waves in river channels this condition may appear to be impossible, yet it has been observed many times. This hydraulic phenomenon is explained elsewhere.[6]

At locations several miles below the point of pollution, there is no apparent relation between the concentration of pollutants in grab samples and the discharge of the river at the sampling time. The concentration may be high and the discharge also high, or low and the discharge low. At another location farther downstream, the concentration-discharge relation may be back in its original pattern, i.e., concentration inversely proportional to discharge. This indicates that a complete wave cycle has passed.

Since the "slugs" of concentrated pollution move downstream at varying velocities the quantitative effect of pollution on dissolved oxygen concentrations is difficult to correlate with normally associated variables such as discharge, BOD, temperature, and time of flow in the river from the source of pollution. An additional variable which affects dissolved oxygen concentration and which is not encountered on unregulated streams, is the extreme variation in duration of low flow at a sampling station. If the controlled flow is low for only a few hours a day, the dissolved oxygen does not sink to such low concentrations as when the low flow continues for several days or longer.

Water temperature fluctuations will be significant in the summer months inasmuch as the temperature of the released water may be 50 degrees Fahrenheit and the temperature of local inflow over 80 degrees Fahrenheit.

Below pollution sources on regulated streams where it is necessary to make a quantitative evaluation of the pollution load and its detrimental effects, it has been found desirable to establish several sampling stations only a few miles apart. Samples should be collected at each of these stations at relatively frequent intervals throughout a continuous period of about four days, preferably including a week-end low-flow period. Rated stream gages are essential at each sampling point. The time of flow between stations at the various flow levels can then be determined by comparing graphs of concentrations of selected pollutants plotted against time of occurrence at each sampling station.

Additional Effects of a Relatively Small Reservoir, a Short Distance Below a Storage Reservoir

The construction of smaller reservoirs, principally for power generation, downstream from a large storage reservoir, is rather common practice in order to take economic advantage of the stream-flow regulation provided by the larger project. In this discussion a small reservoir is one having a capacity on the order of 75,000 to 100,000 acre feet and a water depth at the dam of perhaps 80 feet.

The principal inflow to the smaller pool is assumed to be the outflow from the upstream storage project with local inflow minor by comparison.

Such small reservoirs may be located immediately below or several miles downstream from the storage project and produce effects on water quality unlike those of a storage reservoir in several respects. As might be expected the mechanism of flow through the pool has a major influence on these effects.

---

6. Discussion of "Translatory Waves in Natural Channels", by M. A. Churchill, Transactions ASCE, 1945, p. 1229.

During the winter months of the year, as in the storage pool, the inflow occupies the entire reservoir cross section as the water advances under the influence of draft, toward the dam. Vertical circulation and therefore, mixing and aeration are practically continuous. During the spring months, however, warmer directly local inflow and atmospheric warming of the water in the pool combine to promote thermal stratification. The principal volume of inflow remains cold, however, since it is supplied from the bottom of the upstream storage pool. As spring advances, the temperature of the water in the upper strata continues to rise above that of the cold inflow and the inflow begins to pass through the pool as a density underflow along the bottom. The velocity of the underflow is measured in tenths of a foot per second, the actual velocity being dependent primarily upon the difference in density between the pooled and inflowing water, the volume of inflow per second, the width of the river valley, and the slope of the river bed.

Underflow continues all summer and fall, being stopped finally in early winter by the atmospheric cooling of the overlying waters to the temperature of the inflow.

During the period of underflow the inflowing water is isolated from the water surface and little mixing occurs at the sloping interface and thermocline between the moving water and the overlying still water. Thus, with reaeration prevented, the BOD of any wastes discharged to the river at locations between the two reservoirs proceeds to reduce the dissolved oxygen concentration in the underflowing water as it passes through the downstream pool. Studies have demonstrated substantial agreement between observed dissolved oxygen concentrations in the water discharged at the small dam and oxygen concentrations computed for this location from BOD values for the inflowing water after a period of incubation equivalent to the time of flow through the pool.

In those situations where heavy pollution of the inflowing waters exists, the BOD of the underflowing waters may be so great as to exhaust completely the available dissolved oxygen during the relatively short time of flow through the pool. It is apparent that if the discharge at the dam is shut off for a period of time, say a week or more, septic conditions will be produced in the underflowing water that is near the dam. The longer the cut off, the larger will be the accumulated volume of cold, septic, water.

When heavily polluted inflow is allowed to pass through the pool at its normal underflow velocity, it will be discharged at the dam within a week or so of the time it entered the pool. Dissolved oxygen in the outflow will be quite low, if not zero, and there will be a considerable portion of the first-stage BOD, and practically all the second-stage BOD, still unsatisfied. Inasmuch as the rate of inflow will be variable, the concentration of pollution in the inflow and outflow will be variable also.

Even though polluted water requires only a week to pass through the pool, the proportion of live coliforms that pass through is very low, usually being only a few percent. Thus, even a relatively small reservoir is a very efficient purification device so far as bacteria are concerned, even though flow passes through it in the most short-circuited manner.

Numerous observations in reservoirs of the Tennessee Valley have shown that when a density underflow of cold water passes the mouth of a tributary embayment, the cold water will flow upstream into the embayment even though opposed hydraulically by local inflow into the head of the embayment. This condition may have serious consequences at municipal or industrial water intakes, as at Harriman, Tennessee.[7]

7. "Effect of Density Currents Upon Raw Water Quality", by M. A. Churchill, Journal AWWA, April 1947.

By virtue of the fact that practically all pollution carried into the pool by the cold inflow will pass on through along the bottom, the water of the epilimnion is usually of good quality, particularly in the downstream end of the pool.[8] The epilimnion is composed of water that entered the pool during the previous winter and was warmed up by the sun sufficiently to stratify it, plus some water from direct local runoff, and plus some water derived from the underflow by exchange mixing. Aeration, sedimentation, and time, combine to reduce the concentration of pollutants in the water of the epilimnion.

If the discharge from the upstream storage reservoir is cut off for several days, the local inflow will constitute the only inflow to the downstream pool. Such local runoff will be warm during the summer months and consequently, it will flow into, and remain in, the upper strata. If the local inflow carries pollution, any suspended or dissolved material will be held in the upper levels of the pool for perhaps months before being discharged at the dam. During this holding period a high degree of natural purification will take place.

When water is discharged from a reservoir through a hydraulic turbine runner and draft tube, it boils up in the tailrace with considerable turbulence. However, as an aeration device the turbulence so created is not very efficient. Numerous observations of dissolved oxygen concentrations in water from the scroll case and in the tailrace indicate that dissolved oxygen concentrations are usually increased less than one part per million. Naturally the greater the distance to the downstream sampling point, the greater the reaeration.

SUMMARY AND CONCLUSIONS

The construction of a storage reservoir on a stream has a profound effect on its ability to assimilate pollution. Storage alone brings many altered influences into action. The regulation of flows downstream from the dam produces additional influences. It cannot be said categorically that a reservoir will have a net beneficial or detrimental effect because some water uses will be benefited and others may be harmed.

When raw domestic sewage is impounded by a reservoir the well known beneficial effects of time promptly come into play to reduce the numbers of bacteria. This action greatly benefits downstream municipal water supplies. Simultaneously, however, much of the organic matter present in the sewage settles to the bottom to form sludge deposits that produce "bubbly" areas in the overlying waters and floating masses of gas-buoyed, unsightly material. The plant nutrients supplied in the sewage may result in excessive algal growths that can be a visual as well as an olfactory nuisance. Municipal water supplies drawn from the reservoir may be affected by tastes and odors produced by algae and actinomycetes.

Reservoirs have a pronounced smoothing or ironing out effect on variations in mineral and other pollutants added upstream. This facilitates downstream water treatment. The pools reduce natural turbidity greatly inasmuch as they act as tremendous settling basins. However, following an unusually large inflow of muddy surface runoff during the winter months, the entire pool may become turbid and remain so for several weeks.

Thermal stratification in the deep pools during the warmer months of the year separates each pool into two distinct water masses. The warmer upper

8. "Bacteriological Studies of the Fort Loudoun Reservoir", by R. N. Clark and F. W. Kittrell, Journal APHA, March 1948, p. 342-350.

stratum, the epilimnion, is well oxygenated by wind action and algal activity. The hypolimnion, below the thermocline, is composed of cool water remaining from the previous winter. Organic matter derived from natural surface wash and from pollution sources slowly uses up the dissolved oxygen present in the waters of the hypolimnion. In so doing, however, the B.O.D. is partially to almost completely satisfied. The cool water discharged from the low elevation power outlets is thus low in dissolved oxygen but also low in B.O.D. Water in such a condition would be expected to absorb oxygen very rapidly in the open river downstream but cases have been observed where over fifty miles of river, with no added pollution, were required for near saturation to be reached. This situation exists when flows are high. When low flows exist, near saturation is reached in much shorter distances. This is due primarily to the fact that the reaeration coefficient varies approximately inversely with the discharge.

The relatively cold water discharged during the warm season of the year from low elevation power intakes at the dam is very beneficial to downstream industrial concerns using the discharged water for cooling purposes.

If a source of pollution exists immediately below the dam, the low oxygen condition of the water renders the stream incapable of absorbing much of the pollution without serious consequences. Furthermore, the absence of flood flows below the dam allows sludge deposits to accumulate for indefinite periods.

The unsteady nature of releases from hydro power projects presents a whole series of problems in the determination of the pollution absorbing capacity of the controlled river. The inequality of translatory wave travel and of water travel makes this problem more complicated.

In smaller reservoirs downstream from large storage pools, density currents in the summer months are produced by the cold inflow from the upstream pool. These currents often carry pollution directly through the smaller reservoir along the bottom. Such currents also may carry pollution back into tributary embayment areas that were previously unaffected by main river pollution.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1955

PRESIDENT

WILLIAM ROY GLIDDEN

VICE-PRESIDENTS

Term expires October, 1955:
ENOCH R. NEEDLES
MASON G. LOCKWOOD

Term expires October, 1956:
FRANK L. WEAVER
LOUIS R. HOWSON

DIRECTORS

Term expires October, 1955:
CHARLES B. MOLINEAUX
MERCEL J. SHELTON
A. A. K. BOOTH
CARL G. PAULSEN
LLOYD D. KNAPP
GLENN W. HOLCOMB
FRANCIS M. DAWSON

Term expires October, 1956:
WILLIAM S. LaLONDE, JR.
OLIVER W. HARTWELL
THOMAS C. SHEDD
SAMUEL B. MORRIS
ERNEST W. CARLTON
RAYMOND F. DAWSON

Term expires October, 1957:
JEWELL M. GARRELTS
FREDERICK H. PAULSON
GEORGE S. RICHARDSON
DON M. CORBETT
GRAHAM P. WILLOUGHBY
LAWRENCE A. ELSENER

PAST-PRESIDENTS

Members of the Board

WALTER L. HUBER
DANIEL V. TERRELL

EXECUTIVE SECRETARY
WILLIAM N. CAREY

TREASURER
CHARLES E. TROUT

ASSISTANT SECRETARY
E. L. CHANDLER

ASSISTANT TREASURER
GEORGE W. BURPEE

PROCEEDINGS OF THE SOCIETY

HAROLD T. LARSEN
Manager of Technical Publications

DEFOREST A. MATTESON, JR.
Editor of Technical Publications

PAUL A. PARISI
Assoc. Editor of Technical Publications

COMMITTEE ON PUBLICATIONS

SAMUEL B. MORRIS, *Chairman*

JEWELL M. GARRELTS, *Vice-Chairman*

GLENN W. HOLCOMB
ERNEST W. CARLTON
OLIVER W. HARTWELL
DON M. CORBETT